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The Pyramid Liner Concept

by William P. Walters and Daniel R. Scheffler

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William P. Walters and Daniel R. Scheffler
Weapons and Materials Research Directorate, ARL

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14. ABSTRACT

A shaped charge device was designed from a charge with a four-sided pyramid as the liner. Devices of this nature were first studied by Geiger and Honcia in 1977 and relegated to the area of interesting concepts, but without application. The current study represents probably the first numerical simulations of this charge, including parametric variations of the altitude of the pyramid and the initiation mode of the explosive. The numerical simulations were performed using the CTH hydrocode (shock physics code) developed by Sandia National Laboratories. The liner was made of copper, and the wall thickness of each isosceles triangle comprising the pyramid was identical. The multiple interacting jets provide a wide area of coverage that implies that the device may be useful as a multidirectional cutting charge. A multidirectional charge may be useful for certain applications in the mining, oil well completion, demolition, or military fields.

15. SUBJECT TERMS

shaped charge, pyramid liners, jet growth, jet formation, simulation, hydrocode

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1. Introduction

A numerical study was performed on shaped charges that employed a pyramid as the liner geometry. The CTH hydrocode (McGlaun et al., 1990) developed by Sandia National Laboratories was used in this study. The pyramid had a square base with the diagonal of the base equal to 1.4 cm. The altitude (or height) of the pyramid was varied from 0.5 to 1.31 cm. The thickness of each face of the pyramid was 0.06 cm, and the liner material was copper. The explosive geometry was a right circular cylinder with a diameter of 1.4 cm and a height of 2.31 cm. The charge was bare (i.e., uncased), and cyclotetramethylenetetranitramine (HMX) was used as the explosive fill. Also, a square-shaped explosive fill was studied with a base diagonal of 1.4 cm and a height of 2.31 cm enclosing the 1.31-cm altitude pyramid. The initiation mode was varied for this explosive geometry, including a single-point detonation, a line wave detonation, a four-point detonation, and a five-point detonation.

Geiger and Honcia (1977) conducted earlier studies with square-based pyramidal liners. They presented flash radiographs of six pyramidal liner shapes each with the same base area, the base diagonal being 4.0 cm. The current study is a numerical investigation of square-based pyramidal liners using the January 2002 version of the CTH hydrocode (McGlaun et al., 1990), which is a state-of-the-art, second-order accurate, Eulerian hydrocode under continuous development at Sandia National Laboratories, NM. CTH is capable of solving complex problems in shock physics in one, two, or three dimensions. Previous studies have verified that CTH hydrocode simulations are generally in excellent agreement with experimental data. The code provides several constitutive models, including an elastic-perfectly plastic model with provisions for work hardening and thermal softening, the Johnson-Cook model (Johnson and Cook, 1983), the Zerilli-Armstrong model (Zerilli and Armstrong, 1987), the Steinberg-Guinan-Lund model (Steinberg et al., 1980; Steinberg and Lund, 1989), an undocumented power-law model, and others. Detonation of the high explosive (HE) can be modeled using the programmed burn model, the Chapman-Jouguet volume burn models, or the history variable reactive burn model (Kerley, 1992). Several equation of state (EOS) options are available, including tabular (i.e., SESAME), analytical (ANEOS), Mie-Grüneisen, and Jones-Wilkins-Lee (JWL) (Lee et al., 1968). Material failure occurs when a threshold value of tensile stress or hydrostatic pressure is exceeded. In addition, the Johnson-Cook failure model (Johnson and Cook, 1985) is also available. When failure occurs in a cell, void is introduced until the stress state of the cell is reduced to zero. Recompression is permitted. To reduce the diffusion typically encountered in Eulerian simulations, several advanced material interface tracking algorithms are provided, including the high-resolution interface tracking (HRIT) algorithm (available for two-dimensional [2-D] simulations only), the simple line interface calculation (SLIC) algorithm (Noh and Woodward, 1976), and the Sandia-modified Young's reconstruction algorithm (SMYRA) (Bell and Hertel, 1992). The following sections describe the CTH code input, present the numerical results, and discuss these results.

2. Problem Setup

All simulations were performed in quarter symmetry with the origin of the coordinate system located in the center of the square base of the pyramid and the main jet formation and movement along the +y coordinate direction. The planes of symmetry were located at x = 0 and z = 0. For each of the simulations, the mesh consisted of 130 × 750 × 130 cells with each cell having dimensions of 0.01 × 0.01 × 0.01 cm. The mesh in the y coordinate direction started at −2.5 cm and ended at 5.0 cm. In order to capture the main jet's velocity history, a Lagrangian tracer particle was inserted into the mesh at the <0, −0.02, 0> cm coordinate position.

The copper liners were modeled using standard copper properties for the Johnson-Cook constitutive model (Johnson et al., 1983) and CTH library values for the Mie-Grüneisen EOS. Failure was modeled using a simple tensile pressure criteria such that failure would occur at a tensile pressure of 345.0 MPa. The HMX explosive was treated as a fluid (i.e., it does not support strength). The JWL EOS was used to model the pressure-volume-energy behavior of the detonation products of the HMX explosive using parameters from Dobratz (1981). A simple programmed burn model was used to model explosive initiation.

An input deck used for the liner height study is given in Appendix A for the case of the 0.5-cm liner. Comments included in the input deck give the changes needed to modify the CTH input for the other liner geometries. Appendix B includes the input deck for the detonation initiation study for the one-point initiation case. Comments included in the input deck give the modifications needed for the other included initiation modes.

3. Numerical Results and Discussion

The altitude of the pyramidal liner was varied from 0.5 to 1.31 cm with corresponding pyramid angles (i.e., the angle between opposing faces of the pyramid), varying from 89.4° to 41.4°. The geometry and mass of the explosive and liner for each case are given in Table 1. Figure 1 depicts the initial geometry. Figures 2–6 present the results of the simulations. Each figure represents a different time but the same distance of travel. Each comparison was made before the jet tip had traveled ~5 cm (just before it left the computational mesh). Each figure shows a side view (from the +z direction), a top view (from the +y direction), and a rotated view (rotated 45° about the y-axis then rotated 45° toward the reader to illustrate the three-dimensional [3-D] nature of the jet). While the simulations were performed in quarter symmetry, the geometry was reflected in such a way as to show the whole jet. In all figures, the side views are to the same scale. The top views are also to the same scale in all figures but not to the same scale as the side views. Likewise, the rotated views scale for all figures but not to the side or top views. Figure 2

Table 1. Geometry and mass of the pyramidal liners and cylindrical explosive billets.

Pyramid Altitude (cm)	HE Height (cm)	Pyramid Wall Thickness (cm)	Pyramid Base Diagonal (cm)	Pyramid Angle (°)	Pyramid Mass (g)	Charge Mass (g)
0.50	2.31	0.06	1.40	89.4212	0.15881	1.60387
0.70	2.31	0.06	1.40	70.5288	0.19531	1.57298
0.92	2.31	0.06	1.40	56.5619	0.24082	1.53900
1.00	2.31	0.06	1.40	52.6685	0.25786	1.52665
1.31	2.31	0.06	1.40	41.3975	0.32557	1.47877

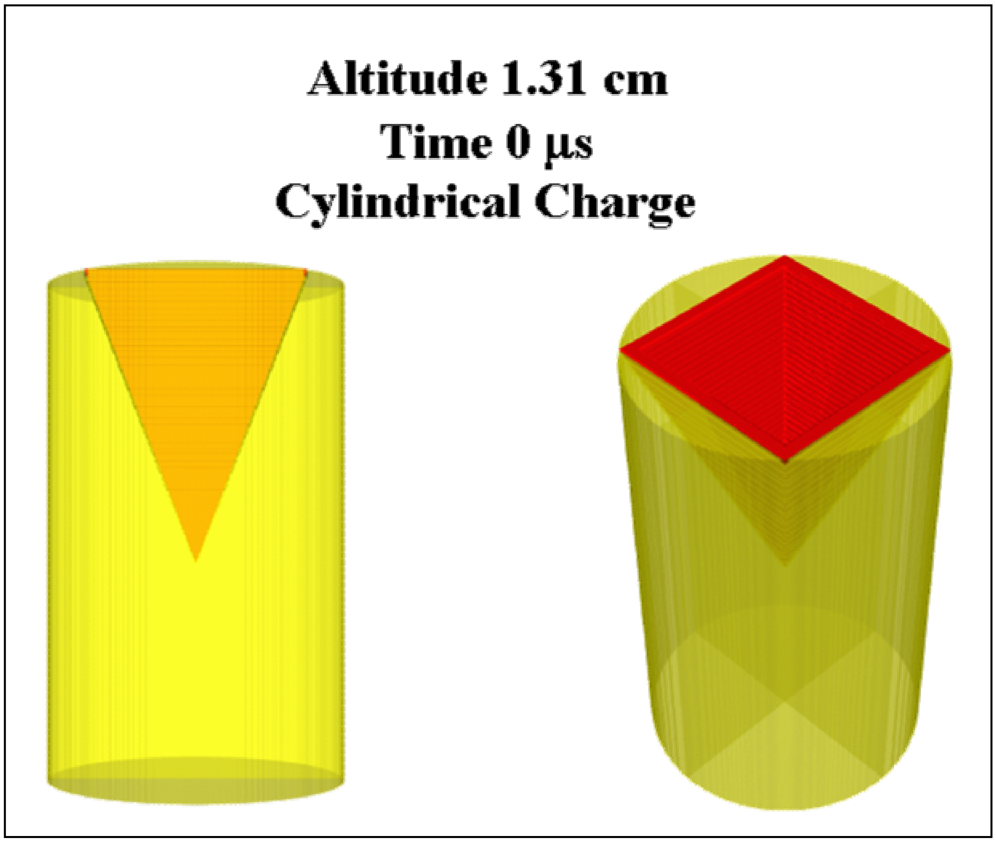

Figure 1. Initial geometry of the 1.31-cm altitude pyramidal liner with a cylindrical explosive billet.

shows the jet from the pyramidal liner with an altitude of 0.5 cm at 12 µs. The jet tip velocity (i.e., the maximum velocity along the jet centerline) was 5.1 km/s. Probes were also used in conjunction with the code to estimate velocities near the tip region and on the trailing wings. These probes are shown as violet dots in these regions and their position is somewhat arbitrary. Figure 2's side view shows a 2-D projection on the x-y plane as viewed from the +z axis of the jet formation and growth. Figure 2's top view shows the top view, again with the probe locations, and Figure 2's rotated view is the rotated view again with the probe locations shown.

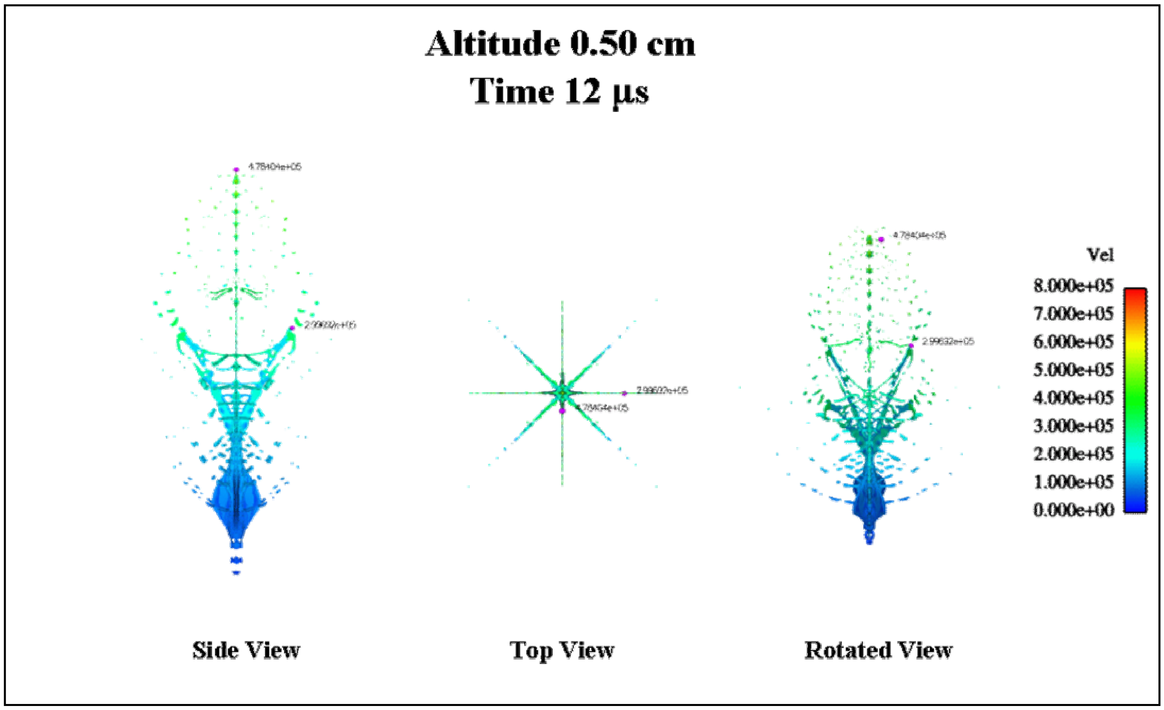

Figure 2. Formation of the 0.50-cm altitude pyramid charge at 12 µs.

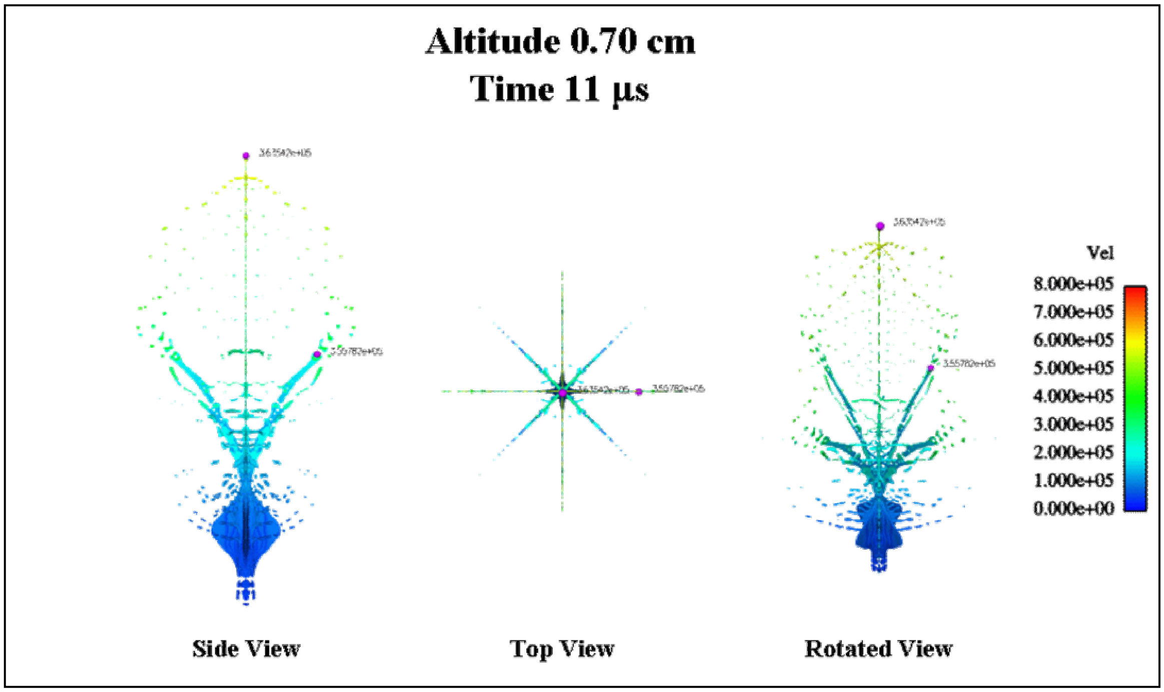

Figure 3. Formation of the 0.70-cm altitude pyramid charge at 11 µs.

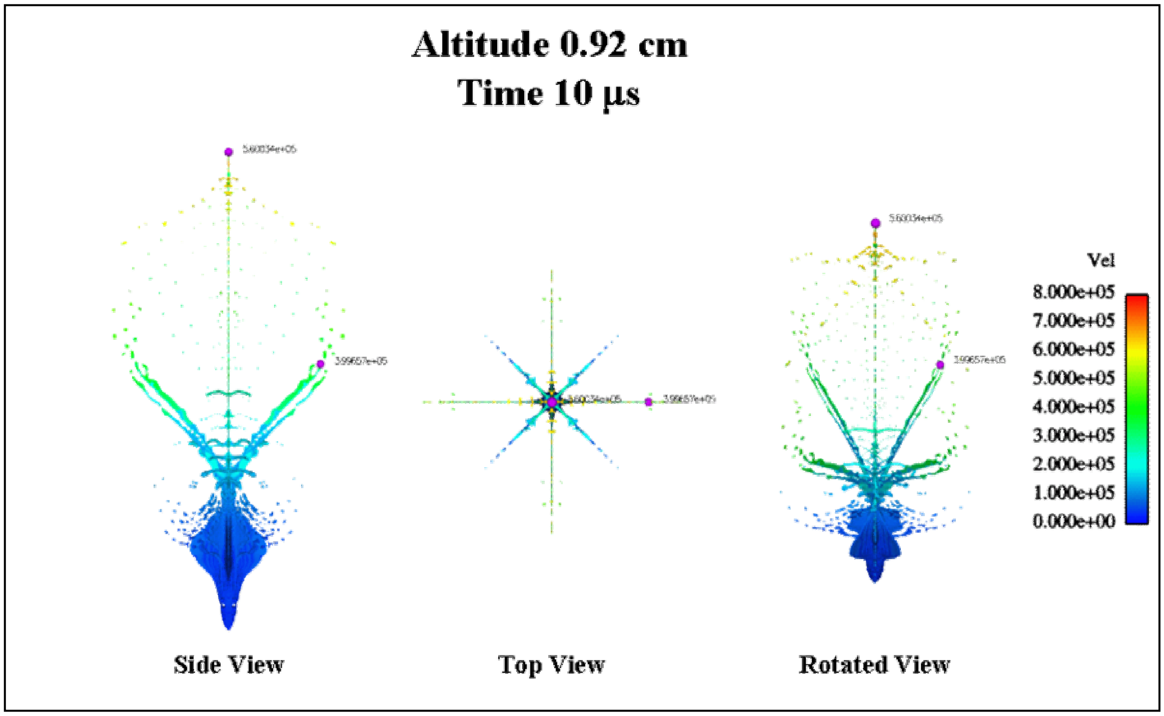

Figure 4. Formation of the 0.92-cm altitude pyramid charge at 10 µs.

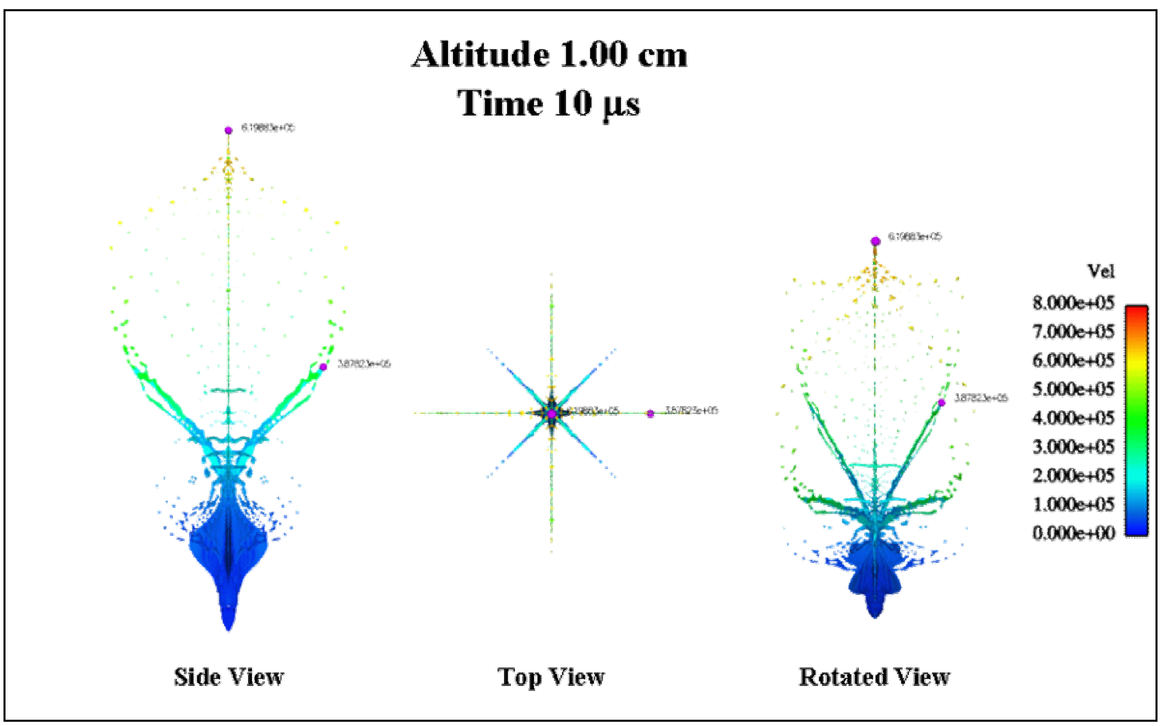

Figure 5. Formation of the 1.00-cm altitude pyramid charge at 10 µs.

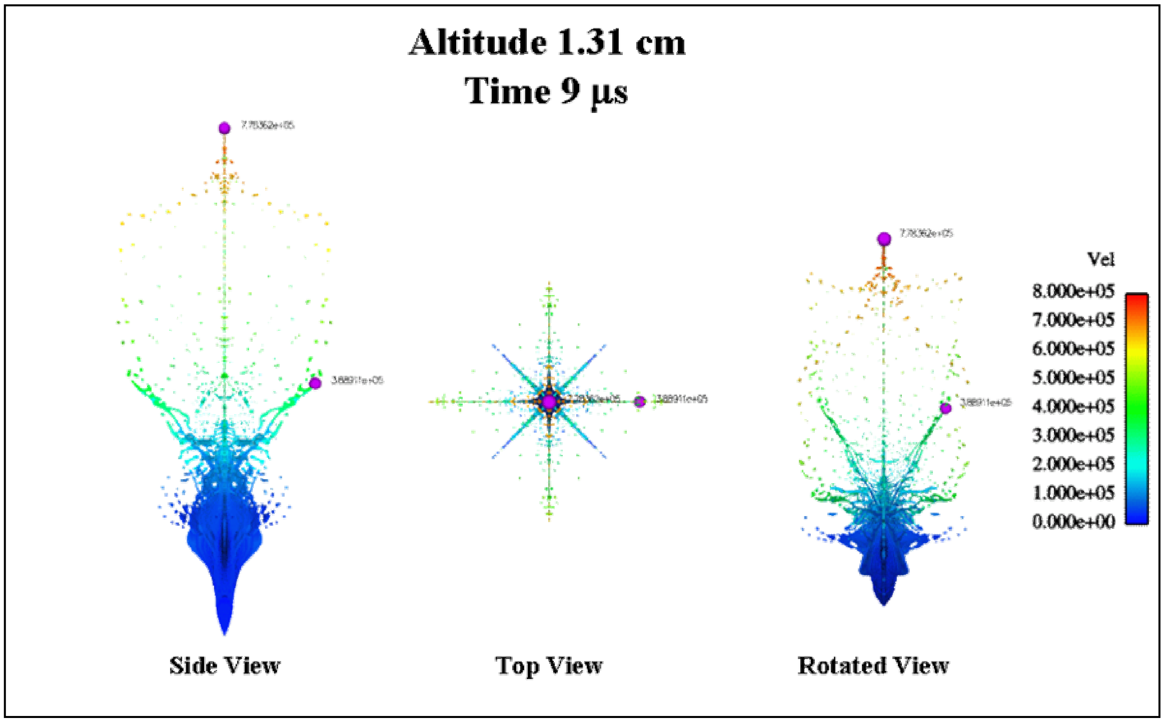

Figure 6. Formation of the 1.31-cm altitude pyramid charge at 9 μs.

Note that the probe near the tip region is not intended to capture the maximum jet particle velocity, just a region near the tip and not necessarily on the centerline of the charge. The collapse of the pyramidal liner illustrates a mechanism to control the distribution of the liner mass. The pyramid walls act as linear or cutting charges and interact with each other causing a spreading of the jet.

Figure 3 shows the same type of data for the pyramidal liner with an altitude of 0.7 cm at 11 μs. The tip velocity was 6.0 km/s, and the wing velocity has increased over the 0.5-cm case. Figure 4 shows the liner with 0.92-cm altitude at 10 μs. The tip velocity was 6.9 km/s, and the estimated wing velocity was about 4 km/s. Figure 5 increases the altitude to 1.0 cm, and at 10 μs the tip velocity is 7.1 km/s. The wing velocity is again about 4 km/s; recall that the positioning of the probe is somewhat arbitrary. Figure 6 shows the 1.31-cm altitude case at 9 μs with a tip velocity of 8.0 km/s and an approximate wing velocity of, again, ~4 km/s. Figure 7 plots the tip or maximum velocity as a function of time for each pyramid altitude up to the maximum run time for each case.

Recall that all jets were allowed to travel approximately the same distance, namely ~5 cm. The jet tip velocity increases as the altitude of the pyramid increases in approximately a linear fashion. Thus, the tip velocity increases as the pyramid apex angle (the angle between opposite faces) decreases, which is analogous to conventional shaped charges with conical liners where the jet tip velocity increases as the conical apex angle decreases. Also, by comparing the rotated views of Figures 2–6, the lateral spread of the jet decreases or the jet becomes more compact

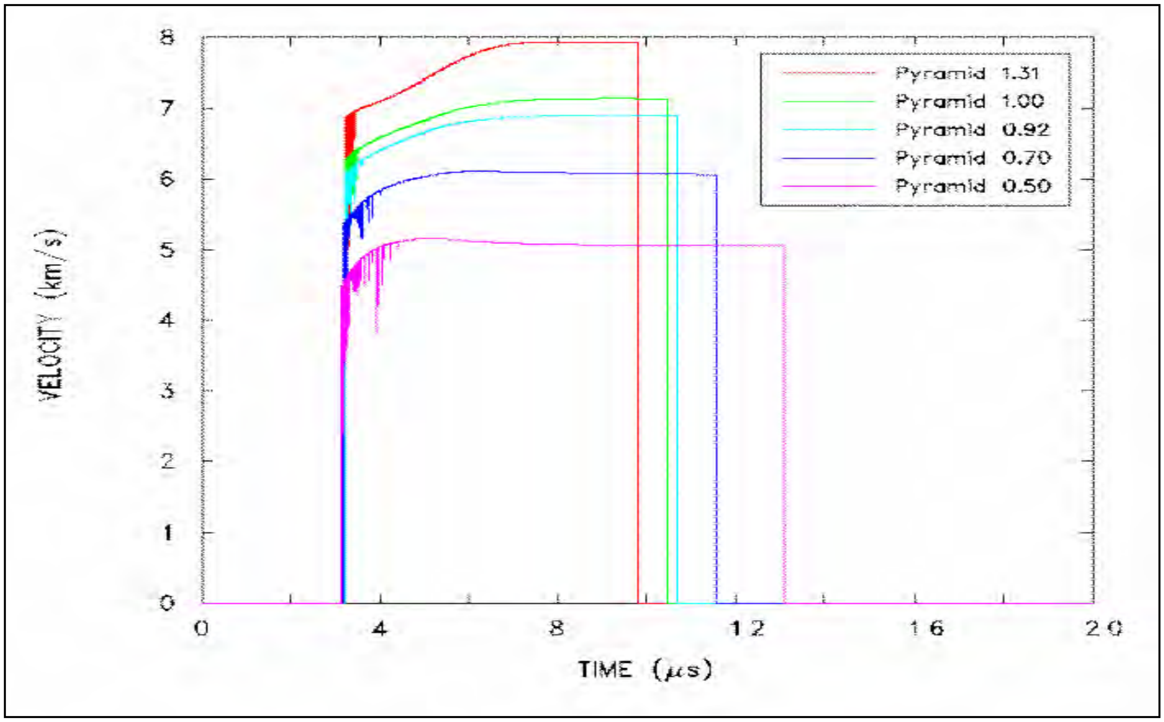

Figure 7. Jet tip velocity vs. time for various altitudes of the pyramidal charge.

as the altitude of the pyramidal liner decreases. Top views in these figures also illustrate this spread. Thus, increasing the apex or pyramid angle implies more compact projectiles (jets), which implies the jet material on the axis has more mass and hence a lower velocity. From the top and rotated views of Figures 2–6, the large, low velocity "blob" near the rear of jet increases as the altitude increases. This blob represents material that has not yet entered the jetting process, most of which will remain as the slug, analogous to conventional conical shaped charges. The numerical results previously presented conceptually agree with the flash x-rays obtained by Geiger and Honcia (1977); see also Walters and Zukas (1989). They reported a cross-shaped cut on target witness plates resulting from the interaction of the pyramidal faces with the cuts being parallel to the base sides of the pyramid. The numerical results presented in Figures 2–6 indicate a double cross, or jets with eight, not four, legs. However, as can be seen from top views in the figures from the color-coded legend, one of the crosses is traveling at a much lower velocity than the other (since it is part of the slug), which would result in minimal penetration into steel. Thus, the numerical simulations are in agreement with the origin of the cross-shaped cut reported by Geiger and Honcia (1977).

The next phase of the study involved picking the fastest jet from the previously mentioned study, namely the 1.31-cm altitude pyramid and changing the explosive geometry from a cylinder to a square with the same base area as the pyramidal liners and the same height as the explosive cylinder. The resulting explosive geometry is shown in Figure 8. The pyramid liner and charge characteristics are shown in Table 1, the only difference being the explosive charge mass which is 0.86799 g for the square explosive billet compared to 1.47877 g for the cylindrical billet. The

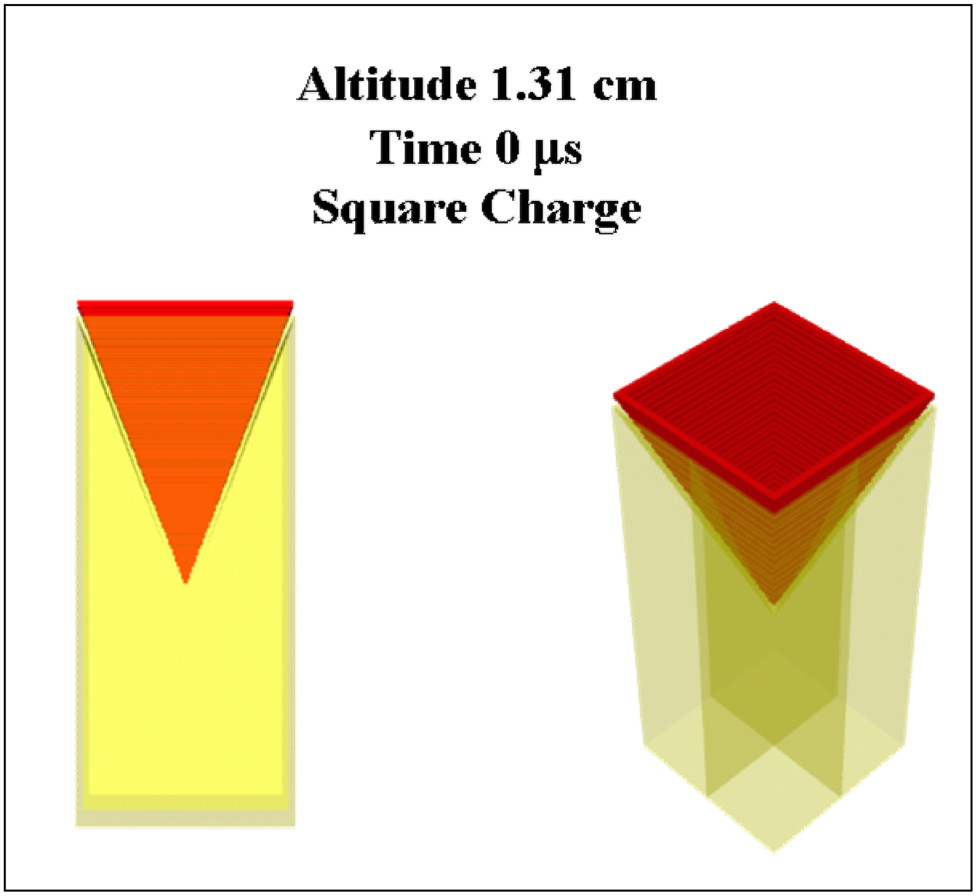

Figure 8. Initial geometry of the 1.31-cm altitude pyramidal liner with a square explosive billet.

first case allowed line wave detonation simultaneously around the four edges of the square base. The second case used four-point detonators at each corner of the base, and the third case used a five-point detonation, the fifth detonator being on the charge centerline. The fourth case was a simple single-point initiation used for direct comparison to the altitude study cases described earlier. These cases are shown in Figures 9–12 using the same format as Figures 2–6. Figure 9 shows the four-point initiation. This case generated the highest tip velocity of 9.7 km/s at 7 μs. Recall the point initiated 1.31-cm altitude case had a tip velocity of 8.0 km/s. The four-point initiation is analogous to a peripheral initiation of a standard shaped charge with a conical liner, which yields a higher tip velocity. This was also the most compact of the non-point initiated cases (recall from the previously mentioned cases, the jet becomes more compact as the velocity increases). Note also that the wing velocity is higher for four-point initiation as compared to the line wave or five-point case, based on the arbitrary position of the probe. Note that in these figures (top view), the second cross (from the slug) has not yet emerged and is moving at a very low velocity (i.e., only the fast wings have emerged). The second cross from the slug region emerged due to the larger amount of explosive around the base of the liner with the cylindrical charge (i.e., subcalibration of the liner, as can be seen by comparing Figures 1 and 8). Figure 10 shows the line wave detonation case at 8 μs with a tip velocity of 9.3 km/s. Figure 11 shows

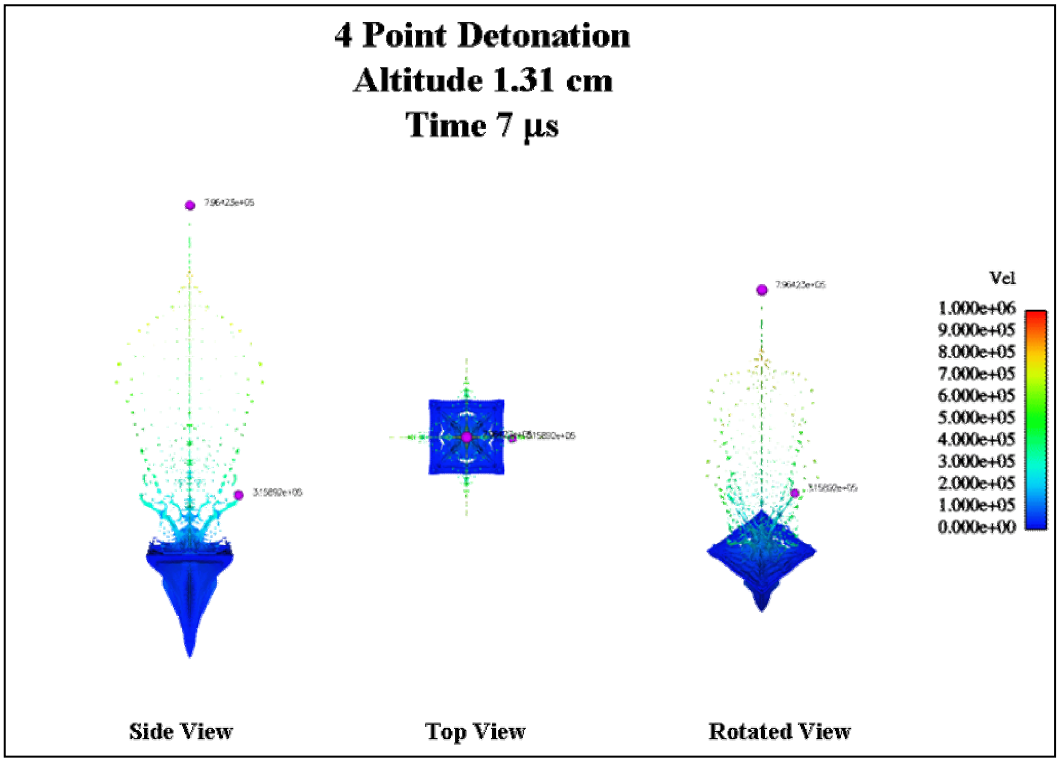

Figure 9. Formation of the 1.31-cm altitude pyramid charge at 7 μs using a square explosive billet and a four-point corner initiation.

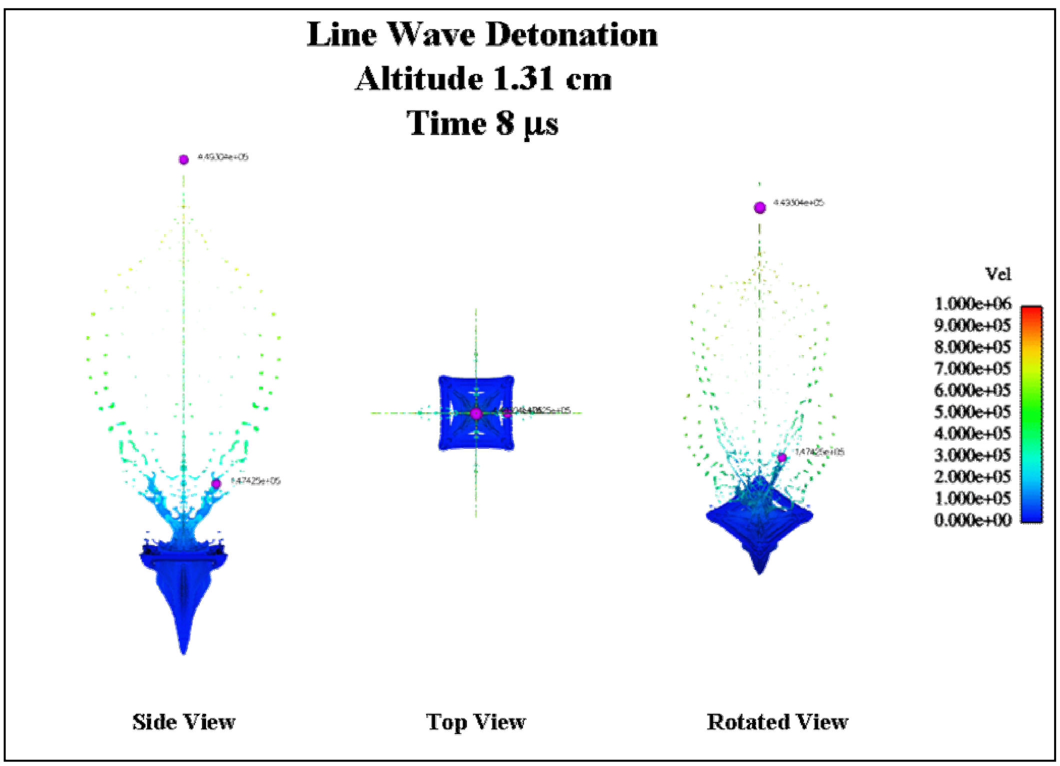

Figure 10. Formation of the 1.31-cm altitude pyramid charge at 8 μs using a square explosive billet and a line wave edge initiation.

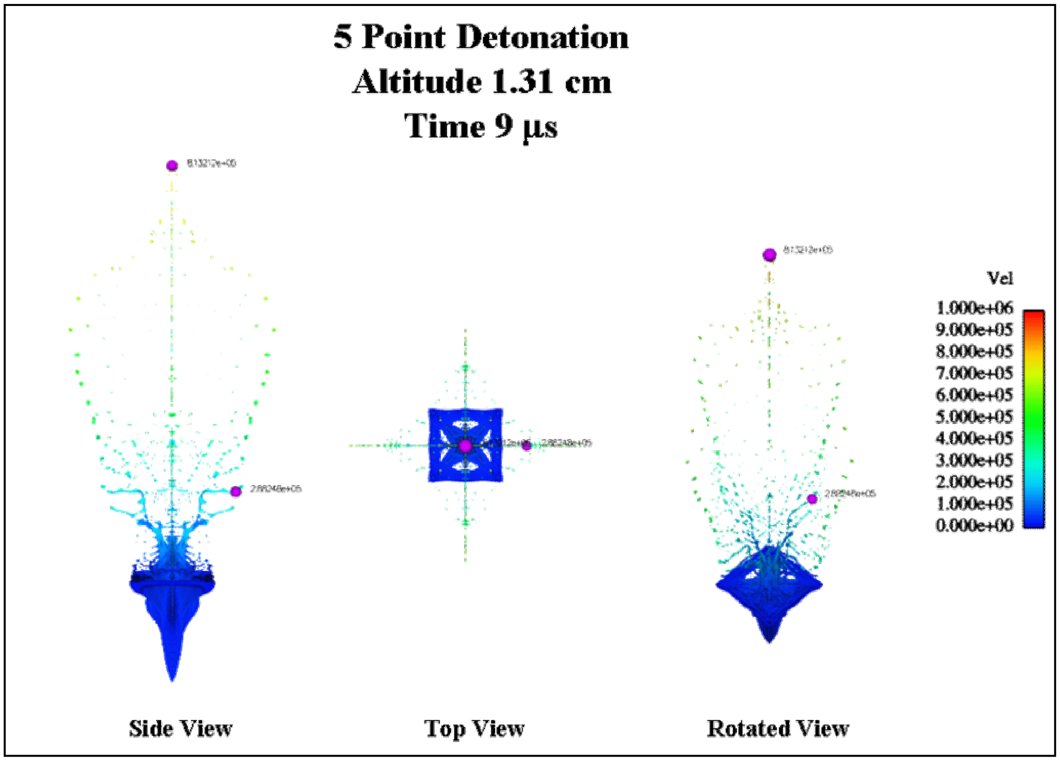

Figure 11. Formation of the 1.31-cm altitude pyramid charge at 9 μs using a square explosive billet and a five-point initiation.

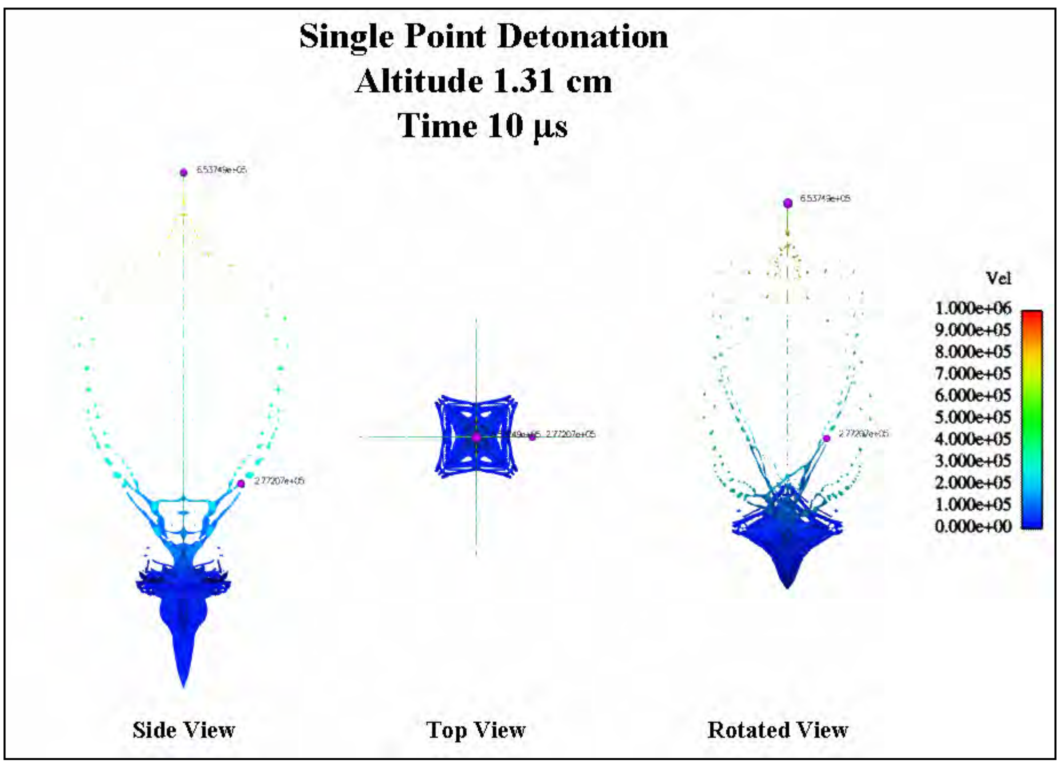

Figure 12. Formation of the 1.31-cm altitude pyramid charge at 10 μs using a square explosive billet and a single center-point initiation.

the five-point initiation at 9 μs with a tip velocity of 8.4 km/s and the case closest to Figure 6. It is likely that the centerline detonator, being closest to the liner apex, dominated the collapse, but a significant velocity increase (0.4 km/s) was observed. Figure 12 is a single center-point initiation case at 10 μs. The tip velocity dropped to 7.2 km/s. This velocity decrease probably results from the inefficient use of explosive since the detonation wave will generate a complex interaction with the corners of the charge. The rarefaction waves from the corner interactions probably influenced the pressure on the liner and hence the liner collapse velocity. However, the jet formation did not appear to be adversely affected. The four-point, five-point, and line wave detonation cases were analogous to a peripheral initiation case, which would minimize the influence of the corners of the square charge. Again, as with all the detonation mode cases, only the fast wings have emerged. Figure 13 plots velocity vs. time for the three detonation modes studied. The time in the plot of Figure 13 is the maximum time when the jet is still within the CTH mesh. Further studies regarding the explosive liner interaction for the square-based charges are recommended.

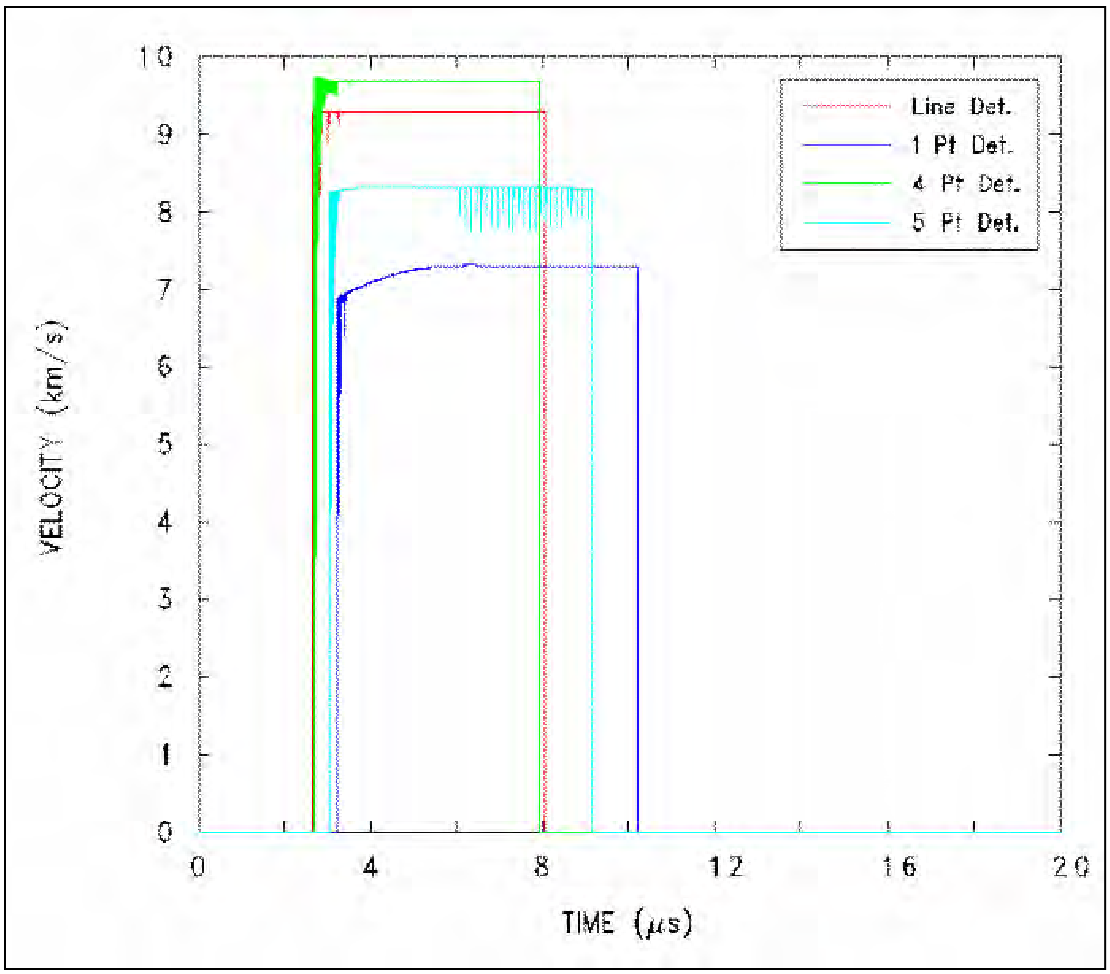

Figure 13. Jet tip velocity vs. time for various initiation modes using the square explosive billet.

4. Conclusion

This study is the first known set of numerical simulations of shaped charges with pyramidal liners and the first investigation of alternate modes of initiation for such charges. A shaped charge with a square base pyramidal liner is a device that can be used to distribute the projectile (jet) mass over a wider area at the expense of removing jet mass from the charge centerline. Devices of this nature may be effective against certain targets. The spread of the projectile can be controlled by varying the altitude or height or the pyramidal liner and altering the mode of initiation from a single symmetric point initiation. Also, the velocity of the projectile can be controlled by the liner altitude and initiation mode; in fact, the jet tip velocity ranged from 5.1 to 9.7 km/s in this study. The results presented herein are in conceptual agreement with the experimental study of Geiger and Honcia (1977) even though different base areas, different altitudes, different wall thicknesses, and even different explosive fills were used. The numerical simulations predicted a “double cross” pattern of the jet formation when the jet is viewed from the top. This double cross was not observed on the steel witness plates from the studies reported by Geiger and Honcia (1977) due to the fact that one “cross” is traveling at a relatively slow velocity compared to the other, since the slower cross is from the slug formation.

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Appendix A. Input Deck for Pyramid Height Study

This appendix appears in its original form, without editorial change.

```
*

* id=1 - Starting baseline configuration
*
*eor*cgenin
*
Pyramid 0.50 cm height
*
control
  ep
  mmp
endcontrol
*
mesh
  block  geometry 3dr  type e
    x0=0.0
      x1  n=130  dxf=0.01 rat=1.
    endx
    y0=-2.5
      y1  n=750  dyf=0.01 rat=1.
    endy
    z0=0.0
      z1  n=130  dzf=0.01 rat=1.
    endz
*     xact=0.0,1.0
*     yact=0.0,5.0
  endblock
endmesh
*
insertion of material
  block 1
*
* NOTE: From of steel cover sit at x-coordinate origin.
*
    package 'Copper Pyramid'
      material 1
      numsub 10
      insert pyramid
        p1      0.4950   0.0000   0.0000
        p2      0.4950   0.0000   0.4950
        p3      0.0000   0.0000   0.4950
        p4      0.0000   0.0000   0.0000
*
* NOTE: Uncomment line to select pyramid height.
*       Currently 0.50 cm Pyramid is the selected height.
*
```

```
      ve      0.0000  -0.5000   0.0000
*       ve      0.0000  -0.7000   0.0000
*       ve      0.0000  -0.9200   0.0000
*       ve      0.0000  -1.0000   0.0000
*       ve      0.0000  -1.3100   0.0000
     endinsert
*
* NOTE: Below is for 0.50 cm height pyramid
*
     delete pyramid
      p1      0.4105   0.0000   0.0000
      p2      0.4105   0.0000   0.4105
      p3      0.0000   0.0000   0.4105
      p4      0.0000   0.0000   0.0000
      ve      0.0000  -0.4105   0.0000
     enddelete
*
* NOTE: Uncomment below for 0.70 cm height pyramid
*
*     delete pyramid
*       p1      0.4215   0.0000   0.0000
*       p2      0.4215   0.0000   0.4215
*       p3      0.0000   0.0000   0.4215
*       p4      0.0000   0.0000   0.0000
*       ve      0.0000  -0.5961   0.0000
*     enddelete
*
* NOTE: Uncomment below for 0.92 cm height pyramid
*
*     delete pyramid
*       p1      0.4268   0.0000   0.0000
*       p2      0.4268   0.0000   0.4268
*       p3      0.0000   0.0000   0.4268
*       p4      0.0000   0.0000   0.0000
*       ve      0.0000  -0.7934   0.0000
*     enddelete
*
* NOTE: Uncomment below for 1.00 cm height pyramid
*
*     delete pyramid
*       p1      0.4280   0.0000   0.0000
*       p2      0.4280   0.0000   0.4280
*       p3      0.0000   0.0000   0.4280
*       p4      0.0000   0.0000   0.0000
*       ve      0.0000  -0.8647   0.0000
*     enddelete
```

```
*
* NOTE: Uncomment below for 1.31 cm height pyramid
*
*     delete pyramid
*       p1     0.4308   0.0000   0.0000
*       p2     0.4308   0.0000   0.4308
*       p3     0.0000   0.0000   0.4308
*       p4     0.0000   0.0000   0.0000
*       ve     0.0000  -1.1402   0.0000
*     enddelete
    endpackage
*
    package 'HMX Explosive'
      material 2
      numsub 10
      insert cylinder
        ce1     0.0000   0.0000   0.0000
        ce2     0.0000  -2.3100   0.0000
        radius 0.7
      endi
      delete pyramid
        p1     0.4950   0.0000   0.0000
        p2     0.4950   0.0000   0.4950
        p3     0.0000   0.0000   0.4950
        p4     0.0000   0.0000   0.0000
*
* NOTE: Uncomment line to select pyramid height.
*       Currently 0.50 cm Pyramid is the selected height.
*
        ve     0.0000  -0.5000   0.0000
*       ve     0.0000  -0.7000   0.0000
*       ve     0.0000  -0.9200   0.0000
*       ve     0.0000  -1.0000   0.0000
*       ve     0.0000  -1.3100   0.0000
      enddelete
    endpackage
*
  endblock
endinsertion
*
epdata
*
  matep 1  johnson-cook copper poisson 0.34
  vpsave
  mix 3
endep
```

```
*
eos
  mat1 mgrun  copper
  mat2 jwl    hmx
endeos
*
heburn
  material 2  d 9.11e5  pre 1.0e12
    dp 0.000 -2.3099 0.000 ti 0.0  radius 0.05
endheburn
*
tracer
  add  0.0  -0.02    0.0
endtracer
*
*eor*cthin
*
Pyramid 0.50 cm height
*
control
  tstop=20.e-6
  cpshift=900.
  rdumpf=3600
  ntbad 100000000
endcontrol
*
*restart
*  time=3.0e-6
*endr
*
cellthermo
  mmp2
endcell
*
convct
  convect=1
  interface=high
endc
*
discard
*  material 1  density  -.001 pressure 1.0e12  ton 1.1e-6
  material 2  density -0.01  pressure 5.0e6   ton 2.0e-6 toff 4.0e-6
  material 2  density 10.00  pressure 1.0e12  ton 3.0e-6 toff 4.1e-6
endd
*
edit
```

```
  shortt
    time=0.  dtf=10000.
  ends
  longt
    time=0.  dtf=10000.
  endl
  plott
    time=0.  dtf=0.05e-6
  endp
  plotdata
    volume
    mass
    temperature
    pressure
    velocity
  endplotdata
  restt
    time=0   dtf=1.e-6
  endr
  histc
    cycle=0  dcfreq=1
      htracer1
  endh
endedit
*
mindt
  time=0.  dtmin=1.0e-13
endm
*
fracts
  pressure
  pfrac1=-3.45e9
  pfrac2= -1e9
  pfmix =-5.0E20
  pfvoid=-5.0E20
endf
*
boundary
  bhydro
    block=1
      bxbot 0
      bxtop 1
      bybot 1
      bytop 1
      bzbot 0
      bztop 1
```

```
    endb
  endh
endb
*
*eor*pltin
*
```

INTENTIONALLY LEFT BLANK.

Appendix B. Input Deck for Detonation Location Study

This appendix appears in its original form, without editorial change.

```
*
* id=1 - Starting baseline configuration
*
*eor*cgenin
*
Pyramid 1.31 cm height 1 point detonation
*
control
  ep
  mmp
endcontrol
*
mesh
  block  geometry 3dr  type e
    x0=0.0
      x1  n=130  dxf=0.01 rat=1.
    endx
    y0=-2.5
      y1  n=750  dyf=0.01 rat=1.
    endy
    z0=0.0
      z1  n=130  dzf=0.01 rat=1.
    endz
*     xact=0.0,1.0
*     yact=0.0,5.0
  endblock
endmesh
*
insertion of material
  block 1
*
* NOTE: From of steel cover sit at x-coordinate origin.
*
    package 'Copper Pyramid'
      material 1
      numsub 10
      insert pyramid
        p1      0.4950   0.0000   0.0000
        p2      0.4950   0.0000   0.4950
        p3      0.0000   0.0000   0.4950
        p4      0.0000   0.0000   0.0000
        ve      0.0000  -1.3100   0.0000
      endinsert
      delete pyramid
        p1      0.4308   0.0000   0.0000
        p2      0.4308   0.0000   0.4308
```

```
        p3      0.0000   0.0000   0.4308
        p4      0.0000   0.0000   0.0000
        ve      0.0000  -1.1402   0.0000
      enddelete
    endpackage
*
    package 'HMX Explosive'
      material 2
      numsub 10
      insert box
        p1      0.0000   0.0000   0.0000
        p2      0.4950  -2.3100   0.4950
      endi
      delete pyramid
        p1      0.4950   0.0000   0.0000
        p2      0.4950   0.0000   0.4950
        p3      0.0000   0.0000   0.4950
        p4      0.0000   0.0000   0.0000
        ve      0.0000  -1.3100   0.0000
      enddelete
    endpackage
*
  endblock
endinsertion
*
epdata
*
  matep 1  johnson-cook copper poisson 0.34
  vpsave
  mix 3
endep
*
eos
  mat1 mgrun  copper
  mat2 jwl    hmx
endeos
*
heburn
  material 2  d 9.11e5  pre 1.0e12
*
* NOTE: Uncomment appropriate line for selected initiation type.
*
* NOTE: 1 Point initiation. Currently selected.
*
    dp 0.000 -2.3099 0.000 ti 0.0  radius 0.05
*
```

```
* NOTE: 4 Point initiation. Currently not selected.
*
*    dp 0.495 -2.3099 0.495 ti 0.0  radius 0.05
*
* NOTE: 5 Point initiation. Currently not selected.
*
*    dp 0.495 -2.3099 0.495 ti 0.0  radius 0.05
*    dp 0.000 -2.3099 0.000 ti 0.0  radius 0.05
*
* NOTE: Peripheral Line initiation. Currently not selected.
*
*    dl 0.495 -2.3099 0.000 to 0.495 -2.3099 0.495 ti 0.0  radius 0.05
*    dl 0.000 -2.3099 0.495 to 0.495 -2.3099 0.495 ti 0.0  radius 0.05
endheburn
*
tracer
  add  0.0  -0.02    0.0
endtracer
*
*eor*cthin
*
Pyramid 1.31 cm height 1 point detonation
*
control
  tstop=20.e-6
  cpshift=900.
  rdumpf=3600
  ntbad 100000000
endcontrol
*
*restart
*  time=3.0e-6
*endr
*
cellthermo
  mmp2
endcell
*
convct
  convect=1
  interface=high
endc
*
discard
*  material 1  density  -.001 pressure 1.0e12  ton 1.1e-6
  material 2  density -0.01  pressure 5.0e6   ton 2.0e-6 toff 4.0e-6
```

```
  material 2  density 10.00  pressure 1.0e12  ton 3.0e-6 toff 4.1e-6
endd
*
edit
  shortt
    time=0.  dtf=10000.
  ends
  longt
    time=0.  dtf=10000.
  endl
  plott
    time=0.  dtf=0.05e-6
  endp
  plotdata
    volume
    mass
    temperature
    pressure
    velocity
  endplotdata
  restt
    time=0   dtf=1.e-6
  endr
  histc
    cycle=0  dcfreq=1
      htracer1
  endh
endedit
*
mindt
  time=0.  dtmin=1.0e-13
endm
*
fracts
  pressure
  pfrac1=-3.45e9
  pfrac2= -1e9
  pfmix =-5.0E20
  pfvoid=-5.0E20
endf
*
boundary
  bhydro
    block=1
      bxbot 0
      bxtop 1
```

```
      bybot 1
      bytop 1
      bzbot 0
      bztop 1
    endb
  endh
endb
*
*eor*pltin
*
```

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